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**APPLICATION
FOR
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FOR: LEVEL SHIFTER

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LEVEL SHIFTER

BACKGROUND OF THE INVENTION

1. Field of the Invention

5 The present invention relates to a level shifter for converting a level of an inputted signal into another level to output the signal, and more particularly to a level shifter for level-converting an inputted high level signal into a low level signal.

10 2. Description of the Related Art

 In recent years, an increasing number of microcomputers are designed to have a large number of devices such as an ASIC, a microprocessor, a memory, and a peripheral circuit mounted on a mother board of a computer to satisfy a desirable function.

15 In particular, the ASIC and the microcomputer are designed such that an amplitude of a power source voltage used in the inside becomes smaller, because a reduction in consumption power and operation at a high frequency are required. For example, an internal power source voltage is 2.5 V. This voltage is expected

20 to decrease to 1.8 V, 1.5 V, and 1.2 V in the future.

 In contrast to this, in many cases, in accordance with a JEDEC system interface standard or the like, data input and output operation between respective devices is conducted at 3.3V and a device such as the peripheral circuit is operated at 3.3

25 V. Therefore, occurrence of a situation in which the peripheral circuit is operated at a voltage different from operating voltages of the ASIC and the microcomputer is becoming more frequent. Thus, the ASIC and the microcomputer are provided with

input and output buffers in order to adjust a voltage difference between the inside and the outside by level shifting.

With respect to a first conventional technique, as shown in Fig. 3, there has been generally known, as an input buffer, a level shifter circuit in which a plurality of inverters are connected in series for level shifting, as an input and output buffer (for example, see JP 03-125515 A).

As shown in Fig. 3, the level shifter circuit that shifts a high voltage level to a low voltage level includes a first inverter circuit and a second inverter circuit. The first inverter circuit is composed of a P-type MOS transistor MP11 and an N-type MOS transistor MN11, which have a tolerant voltage of 3.3 V and are connected between a Vdd (1.2 V) terminal and a GND terminal and. The gates of the MOS transistors MP11 and MN11 are commonly connected with an input terminal. The second inverter circuit is composed of a P-type MOS transistor MP12 and an N-type MOS transistor MN12, which have a tolerant voltage of 1.2 V and are connected between the Vdd (1.2 V) terminal and the GND terminal. The gates of the MOS transistors MP12 and MN12 are commonly connected with the drains of the P-type MOS transistor MP11 and the N-type MOS transistor MN11. The output of the level shifter circuit is taken out from the drains of the transistors composing the second inverter circuit.

According to such a structure, it is possible that an input signal having an amplitude of 3.3 V is inverted to outputted as an inverted signal having an amplitude of 1.2 V by the first inverter circuit and then the inverted signal is inverted again to be outputted as a signal which is in phase with the input

signal by the second inverter circuit.

Also, with respect to a second conventional technique, as shown in Fig. 6, there is another level shifter circuit provided with a CMOS inverter INV11 and a current mirror flip-flop latch circuit composed of P-type MOS transistors MP13 and MP14 and N-type MOS transistors MN13 and MN14 (for example, see JP 11-239051 A).

However, when the level shifter circuit is composed of the two inverter circuits as described in the first conventional technique, as shown in Figs. 4A to 4F, a duty ratio of an output signal V_{out} reduces with respect to an input signal V_{in} , as a source voltage of the P-type MOS transistor of the first inverter circuit decreases.

Hereinafter, the description of the operation of the first inverter circuit will be made in the case where a threshold voltage V_{tn} of the N-type MOS transistor is set to 0.5 V, a threshold voltage V_{tp} of the P-type MOS transistor is set to 0.5 V, an amplitude of the input signal V_{in} is set to 3.3 V, and V_{dd} is set to 1.2 V.

Referring to Fig. 5, description will be made with respect to input and output voltage waveforms of the first inverter circuit. In the case where the input signal V_{in} increases from 0 V to 3.3 V, because the threshold voltage of the N-type MOS transistor is 0.5 V, the N-type MOS transistor MN11 is turned on at a time when V_{in} reaches 0.5 V. Then, an output signal V_{mid} of the first inverter circuit decreases from 1.2 V to 0 V. In contrast to this, in the case where V_{in} decreases from 3.3 V to 0 V, the P-type MOS transistor MP11 is turned on at

a time when V_{in} reaches 0.7 V (note that, because the threshold voltage of the P-type MOS transistor is 0.5 V and the source thereof is connected with the terminal ($V_{dd} = 1.2$ V), 1.2 V - 0.5 V = 0.7 V is obtained). Then, the output signal V_{mid} of the first inverter circuit increases from 0 V to 1.2 V. Because only V_{dd} (= 1.2 V) is applied to the source of the P-type MOS transistor, a time period T_1 from the time at which V_{in} rises from 0 V to the time at which the N-type MOS transistor turns on is different from a time period T_2 from the time at which V_{in} falls from 3.3 V to the time at which the P-type MOS transistor turns on. Thus, a problem is caused in that a duty ratio of the output signal V_{mid} is different from a duty ratio of the input signal V_{in} in the first inverter circuit.

With respect to the second conventional technique, when V_{in} falls from 3.3 V, V_{in} is inverted by the inverter INV11 and transferred to the N-type MOS transistor MN14 to thereby turn on the N-type MOS transistor MN14, which causes a voltage of an output signal V_{out} to become 0 V. On the other hand, when V_{in} rises from 0 V, the N-type MOS transistor MN13 is turned on, so that a charge is pulled from the gate of the P-type MOS transistor MP14, which causes the voltage of the output signal V_{out} to become 1.2 V. As described above, the output signal V_{out} is determined when a gate electrode of any one of the N-type MOS transistors MN13 and MN14 becomes 3.3 V. When the output signal V_{out} becomes 0 V, only the N-type MOS transistor MN14 is turned on, that is, the output is changed by one stage gate. In contrast to this, when the output signal V_{out} becomes 1.2 V, the N-type MOS transistor MN13 is turned on and then the P-type

MOS transistor MP14 is turned on. That is, the output is changed by two stage gates. Accordingly, timing of the output in the case where the output signal Vout rises is different from timing of the output in the case where the output signal Vout falls.

5 Thus, as in the case of the first conventional technique, a problem is caused in that a duty ratio of the output signal Vout is different from a duty ratio of the input signal. Note that, because the inverter INV11 operates at an amplitude of 3.3 V, no substantial delay is caused.

10 The problems with respect to the first and second conventional techniques become remarkable as a frequency of the input signal becomes higher and as an amplitude difference between the input signal and the output signal increases.

15 SUMMARY OF THE INVENTION

Therefore, an object of the present invention is to provide a level shifter circuit in which a change in duty ratio can be reduced even when an amplitude difference between an input signal and an output signal increases, and in which a stable output
20 signal can be supplied even when the input signal becomes a high frequency.

A first level shifter according to the present invention includes:

a first transistor connected between a first power source
25 line and an output node;

a second transistor connected between the output node and a second power source line;

a third transistor connected between the first power source

line and the output node;

a fourth transistor connected between the output node and the second power source line; and

a control circuit that causes the second transistor and the fourth transistor to turn on when an input signal is of a first level, and causes the third transistor and the first transistor to turn on when the input signal is of a second level different from the first level,

in which a gate tolerant voltage of the first transistor is smaller than a gate tolerant voltage of the third transistor and a gate tolerant voltage of the fourth transistor is smaller than a gate tolerant voltage of the second transistor.

A second level shifter according the present invention includes:

a first transistor of a first conductivity type having a first gate tolerant voltage, which is connected between a first power source line and a first node, in which a gate thereof receives an input signal;

a second transistor of a second conductivity type having a second gate tolerant voltage smaller than the first gate tolerant voltage, which is connected between a second power source line and a second node, in which a gate thereof is connected with the first node;

a third transistor of the first conductivity type having the first gate tolerant voltage, which is connected between the second node and the first power source line, in which a gate thereof receives an inverted input signal of the input signal;

a fourth transistor of the second conductivity type having

the first gate tolerant voltage, which is connected between the second power source line and a third node, in which a gate thereof receives the input signal;

5 a fifth transistor of the second conductivity type having the second gate tolerant voltage, which is connected between the second power source line and the second node, in which a gate thereof receives the inverted input signal; and

10 a sixth transistor of the first conductivity type having the second gate tolerant voltage, which is connected between the second node and the first power source line, in which a gate thereof is connected with the third node.

A third level shifter according to the present invention includes:

15 a first transistor of a first conductivity type, which is connected between a first power source line and a first node, in which a control terminal thereof is connected with a second node;

20 a second transistor of the first conductivity type, which is connected between the first power source line and the second node, in which a control terminal thereof is connected with the first node;

25 a third transistor of a second conductivity type, which is connected between the first node and a second power source line, in which a control terminal thereof receives an input signal;

a fourth transistor of the second conductivity type, which is connected between the second node and the second power source line, in which a control terminal thereof receives an inverted

input signal of the input signal;

a fifth transistor of the first conductivity type, which is connected between the first power source line and the second node, in which a control terminal thereof receives the inverted
5 input signal;

a sixth transistor of the second conductivity type, which is connected between the second node and the second power source line, in which a control terminal thereof is connected with a third node;

10 a seventh transistor of the first conductivity type, which is connected between the first power source line and the third node, in which a control terminal thereof receives the input signal; and

a eighth transistor of the second conductivity type, which
15 is connected between the third node and the second power source line, in which a control terminal thereof is connected with the second node,

in which each of the first, second, sixth, and eighth transistors operates in a saturation region in accordance with
20 a level of the input signal, and each of the third, fourth, fifth, and seventh transistors operates in a non-saturation region independently of the level of the input signal.

According to the above-mentioned structures, the rise and the fall of the output signal are caused at the same timing after
25 the input signal is changed. Thus, a duty ratio of the output signal is not changed.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

Fig. 1 is a circuit diagram showing a structure of a level shifter according to an embodiment of the present invention;

Figs. 2A to 2F show waveforms of an input signal and an output signal in the level shifter according to the embodiment
5 of the present invention;

Fig. 3 is a circuit diagram showing a first conventional level shifter circuit;

Fig. 4A to 4F show waveforms of an input signal and an output signal in the first conventional level shifter circuit;
10

Fig. 5 shows an input and output relationship in a first stage inverter of the first conventional level shifter circuit; and

Fig. 6 is a circuit diagram showing a second conventional level shifter circuit.
15

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Hereinafter, an embodiment of the present invention will be described with reference to the drawings. The description
20 will be specifically made based on the embodiment.

Referring to Fig. 1, the embodiment of the present invention will be described.

In this embodiment description will be made of a level shifter in the case where a level of an input signal V_{in} having
25 3.3 V is shifted to a level of an output signal V_{out} having 1.2 V.

A level shifter of the present invention includes a first level shifter circuit 1 and a second level shifter circuit 2.

The first level shifter circuit 1 is composed of P-type MOS transistors MP1 and MP2 and N-type MOS transistors MN1 and MN2. The P-type MOS transistor MP1 is formed from a transistor having a gate tolerant voltage of 1.2 V. The source thereof is connected with a Vdd (1.2 V) terminal. The P-type MOS transistor MP2 is formed from a transistor having a gate tolerant voltage of 1.2 V, similarly to the P-type MOS transistor MP1. The source of the P-type MOS transistor MP2 is connected with the Vdd (1.2 V) terminal, the drain thereof is connected with the gate of the P-type MOS transistor MP1, the gate thereof is connected with the drain of the P-type MOS transistor MP1. The N-type MOS transistor MN1 is formed from a transistor having a gate tolerant voltage of 3.3 V. The source thereof is connected with a GND terminal, the drain thereof is connected with the drain of the P-type MOS transistor MP1, and the gate thereof receives an input signal Vin. The N-type MOS transistor MN2 is formed from a transistor having a gate tolerant voltage of 3.3 V, similarly to the N-type MOS transistor MN1. The source of the N-type MOS transistor MN2 is connected with the GND terminal, the drain thereof is connected with the drain of the P-type MOS transistor MP2, and the gate thereof receives an inverted signal VinB of the input signal Vin.

The second level shifter circuit 2 is composed of P-type MOS transistors MP3 and MP4 and N-type MOS transistors MN3 and MN4.

The P-type MOS transistor MP3 is formed from a transistor having a gate tolerant voltage of 3.3 V, and the source thereof is connected with the Vdd (1.2 V) terminal, and the gate thereof

receives the input signal V_{in} . The P-type MOS transistor MP4 is formed from a transistor having a gate tolerant voltage of 3.3 V, similarly to the P-type MOS transistor MP3. The source of the P-type MOS transistor MP4 is connected with the Vdd (1.2 V) terminal and the gate thereof receives the inverted signal V_{inB} . The N-type MOS transistor MN3 is formed from a transistor having a gate tolerant voltage of 1.2 V, the source thereof is connected with the GND terminal, the drain thereof is connected with the drain of the P-type MOS transistor MP3, and the gate thereof is connected with the drain of the P-type MOS transistor MP4. The N-type MOS transistor MN4 is formed from a transistor having a gate tolerant voltage of 1.2 V as in the case of the N-type MOS transistor MN3. The source of the N-type MOS transistor MN4 is connected with the GND terminal, the drain thereof is connected with the drain of the P-type MOS transistor MP4, and the gate thereof is connected with the drain of the P-type MOS transistor MP3.

Note that a connection point between the P-type MOS transistor MP1 and the N-type MOS transistor MN1 that compose the first level shifter circuit is connected with a connection point between the P-type MOS transistor MP3 and the N-type MOS transistor MN3 that compose the second level shifter circuit. Therefore, an output signal of a negative logic (amplitude is 1.2 V) to an input signal can be taken out (negative logic output nodes). Similarly, a connection point between the P-type MOS transistor MP2 and the N-type MOS transistor MN2 that compose the first level shifter circuit is connected with a connection point between the P-type MOS transistor MP4 and the N-type MOS

transistor MN4 that compose the second level shifter circuit. Therefore, the output signal V_{out} of a positive logic (amplitude is 1.2 V) to the input signal can be taken out (positive logic output nodes).

5 Next, the operation of the level shifter of the present invention will be separately described with respect to the case where the input signal V_{in} decreases from 3.3 V to 0 V and the case where the input signal V_{in} increases from 0 V to 3.3 V. Here, because the inverter INV1 that produces the inverted signal
10 V_{inB} is designed to operate in a saturation region, the description is made with the assumption that the delay time can be neglected.

When the input signal V_{in} decreases from 3.3 V to 0 V, that is, when the input signal V_{in} falls, in the first level
15 shifter circuit 1, the N-type MOS transistor MN1 becomes an off state due to the decrease of the input signal V_{in} to 0 V, and the N-type MOS transistor MN2 becomes an on state because the inverted signal V_{inB} is changed to 3.3 V. When the N-type MOS transistor MN2 is turned on, a potential at an output terminal
20 and a potential at the gate of the P-type MOS transistor MP1 are reduced, so that the P-type MOS transistor MP1 becomes an on state. Then, a potential at the gate of the P-type MOS transistor MP2 rises, so that the P-type MOS transistor MP2 becomes an off state. As a result, a potential on the negative
25 logic output node rises through the P-type MOS transistor MP1 and a potential on the positive logic output node falls through the N-type MOS transistor MN2. At this time, a charge is pulled from the positive logic output node (output terminal) through

the N-type MOS transistor MN2. However, because only a voltage of 1.2 V is applied between the source and the drain of the transistor having a tolerant voltage of 3.3 V, the N-type MOS transistor MN2 operates in a non-saturation region. Therefore, current pulling power (source-drain current) of the N-type MOS transistor MN2 becomes lower than that in the case where the N-type MOS MN2 transistor operates in the saturation region. Thus, it takes a long time before the output terminal reaches 0 V.

In the second level shifter circuit 2, similarly to the first level shifter circuit, the P-type MOS transistor MP3 becomes an on state in response to the fall of the input signal V_{in} and the P-type MOS transistor MP4 becomes an off state in response to the inverted signal V_{inB} . When the P-type MOS transistor MP3 is turned on, a potential at the gate of the N-type MOS transistor MN4 rises, so that the N-type MOS transistor MN4 becomes an on state. When the P-type MOS transistor MP4 is turned off, the N-type MOS transistor MN3 becomes an off state. As a result, a potential on the negative logic output node rises through the P-type MOS transistor MP3 and a potential on the positive logic output node falls through the N-type MOS transistor MN4. At this time, because the N-type MOS transistor MN4 becomes the on state by the P-type MOS transistor MP3 turning on, the operation of the N-type MOS transistor MN4 is delayed by a time corresponding to the operation of one stage gate, as compared with the operation of the N-type MOS transistor MN2. However, because the N-type MOS transistor MN4 is composed of the transistor having the tolerant voltage of 1.2 V, it operates

in the saturation region, so that the potential at the output terminal can be reduced at high speed.

Thus, the N-type MOS transistor MN2 first becomes the on state, thereby pulling a charge from the output terminal, while
 5 the N-type MOS transistor MN4 becomes the on state after the delay of a time corresponding to the operation of one stage gate, thereby pulling a charge from the output terminal. Accordingly, a time period before the output signal starts to change in response to a decrease of the input signal to 0 V can be determined by
 10 the N-type MOS transistor MN2 that has the tolerant voltage of 3.3 V and operates in the non-saturation region. In addition, a time period for which the output signal V_{out} decreases from 1.2 V to 0 V can be shortened by the N-type MOS transistor MN4 that has the tolerant voltage of 1.2 V and operates in the
 15 saturation region.

Next, when the input signal V_{in} increases from 0 V to 3.3 V, that is, when the input signal V_{in} rises, in the second level shifter circuit 2, the P-type MOS transistor MP3 becomes an off state because the input signal V_{in} is 3.3 V and the P-type MOS
 20 transistor MP4 becomes an on state because the inverted signal V_{inB} is 0 V. When the P-type MOS transistor MP4 is in the on state, a potential at the output terminal rises. At this time, a potential at the gate of the N-type MOS transistor MN3 rises, so that the N-type MOS transistor MN3 becomes an on state. On
 25 the other hand, because the P-type MOS transistor MP3 is in the off state, a potential at the gate of the N-type MOS transistor MN4 falls, so that the N-type MOS transistor MN4 becomes an off state. As a result, a potential on the positive logic output

node rises through the P-type MOS transistor MP4 and a potential on the negative logic output node falls through the N-type MOS transistor MN3.

At this time, the positive logic output node (output terminal) is charged through the P-type MOS transistor MP4. However, because only a voltage of 1.2 V is applied between the source and the drain of the transistor having the tolerant voltage of 3.3 V, the P-type MOS transistor MP4 operates in the non-saturation region. Therefore, a current supply capacity of the P-type MOS transistor MP4 becomes lower than that in the case where the P-type MOS transistor MP4 operates in the saturation region. Thus, it takes a long time before a potential at the output terminal to rise to 1.2 V.

In the first level shifter circuit, the N-type MOS transistor MN1 becomes an on state because the input signal V_{in} is 3.3 V and the N-type MOS transistor MN2 becomes an off state because the inverted signal V_{inB} is 0 V. When the N-type MOS transistor MN1 becomes the on state, a potential at the gate of the P-type MOS transistor MP2 falls, so that the P-type MOS transistor MP2 becomes an on state. On the other hand, when the N-type MOS transistor MN2 becomes the off state, because the P-type MOS transistor MP2 is in the on state, the P-type MOS transistor MP1 becomes an off state. As a result, a potential on the positive logic output node rises through the P-type MOS transistor MP2 and a potential on the negative logic output node falls through the N-type MOS transistor MN1. At this time, because the P-type MOS transistor MP2 becomes the on state by the N-type MOS transistor MN1 turning on, the operation of the

P-type MOS transistor MP2 is delayed by a time corresponding to the operation of one stage gate (N-type MOS transistor MN1) as compared with the operation of the P-type MOS transistor MP4. However, because the P-type MOS transistor MP2 is composed of
5 the transistor having the tolerant voltage of 1.2 V, the P-type MOS transistor MP2 operates in the saturation region, so that a charge can be pulled from the output terminal at high speed.

Thus, the P-type MOS transistor MP4 first becomes the on state, thereby starting to charge the output terminal, while
10 the P-type MOS transistor MP2 becomes the on state after the delay of a time corresponding to the operation of one stage gate, thereby pulling a charge from the output terminal. Accordingly, a time period before the output signal starts to change in response to an increase of the input signal to 3.3 V can be determined
15 by the P-type MOS transistor MP4 that has the tolerant voltage of 3.3 V and operates in the non-saturation region. In addition, a time period for which the output signal V_{out} increases from 0 V to 1.2 V can be shortened by the P-type MOS transistor MP2 that has the tolerant voltage of 1.2 V and operates in the
20 saturation region.

As described above, in any case where the potential at the output terminal V_{out} increases to 0 V or 1.2 V, the potential is started to be changed by the transistor that operates in the non-saturation region and has a high gate tolerant voltage, and
25 then the potential is changed at high speed by the transistor that operates in the saturation region and has a low gate tolerant voltage. Accordingly, level shifting from a high voltage to a low voltage can be conducted without substantially changing

a duty ratio. Note that a change in potential on the positive logic output node side (output terminal side) is described here. However, even in the negative logic output node side (inverted output terminal side), an inverse change in potential is produced
5 by the same operating principle.

Figs. 2A to 2F show simulation results of a level shifter to which the present invention is applied. A simulation is conducted with respect to the case where an amplitude of the input signal is set to 3.3 V and an amplitude of the output signal
10 decreases from 1.3 V to 0.8 V by 0.1 V. As is apparent from Figs. 2A to 2F, even when a level is shifted to 1.3 V which is a voltage equal to or lower than a half of the input signal, no duty ratio is changed. Further, even when the level is reduced to 0.8 V, no duty ratio is changed.

15 Note that, in this embodiment, the inverter INV1 composed of the transistor having the tolerant voltage of 3.3 V is included in both the level shifter circuits 1 and 2. When two power sources are used in an ASIC, a microprocessor, or the like, the inverter INV1 may be included in both the level shifter circuits 1 and
20 2. However, when a single power source is used, a structure in which the input signal and the inverted signal are supplied from the outside is preferable.

Also, in this embodiment, a start point of a change in potential at the output terminal is determined by the N-type
25 MOS transistor MN2 and the P-type MOS transistor MP4 that have the tolerant voltage of 3.3 V, respectively. A charge and discharge period is determined by a current supply capacity of the P-type MOS transistor MP2 having the tolerant voltage of

1.2 V and a current supply capacity of the N-type MOS transistor MN4 having the tolerant voltage of 1.2 V. Accordingly, it is preferable that the current supply capacity of the P-type MOS transistor MP2 is made larger than that of the P-type MOS transistor MP1, and the current supply capacity of the N-type MOS transistor MN4 is made larger than that of the N-type MOS transistor MN3. Further, in order to rapidly turn on the P-type MOS transistor MP2 and the N-type MOS transistor MN4 that have the tolerant voltage of 1.2 V, respectively, it is preferable that a current supply capacity of the N-type MOS transistor MN1 having the tolerant voltage of 3.3 V is made larger than that of the N-type MOS transistor MN2, and a current supply capacity of the P-type MOS transistor MP3 having the tolerant voltage of 3.3 V is made larger than that of the P-type MOS transistor MP4.

Also, in this embodiment, the level shifter in which the level of the input signal having the amplitude of 3.3 V is shifted to the level of the output signal having the amplitude of 1.2 V is described. In the case of a level shifter in which an input signal having a large amplitude is converted into an output signal having a small amplitude, the amplitudes of the input signal and the output signal can be set as appropriate.

As described above, the positive logic output node of the first level shifter circuit is connected with that of the second level shifter circuit, and the negative logic output node of the first level shifter circuit is connected with that of the second level shifter circuit. Accordingly, the timing at which the output signal rises with respect to the input signal is the

same as the timing at which the output signal falls with respect to the input signal, so that a duty ratio of the output signal is not changed with respect to the input signal. Thus, a level shifter in which the duty ratio is not changed even when an
5 amplitude level difference between the input signal and the output signal increases can be provided.